FORESTRY

FRDA REPORT 146

HERBICIDE APPLICATION FOLLOWED BY PRESCRIBED FIRE TO CONVERT A BRUSHFIELD INTO A CONIFER PLANTATION IN SOUTH COASTAL B.C.: A COMPARISON OF THE INITIAL EFFECTS OF TWO TREATMENTS

by
M.C. Feller

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SUMMARY

A study commenced in 1987 to compare the effectiveness and quantify the effects on the site, of two brown and burn treatments, with respect to vegetative competition, nutrient status, and growth of planted Douglas-fir seedlings, on an ecosystem-specific basis. The two treatments were herbicide application one year followed by burning the next, and herbicide application followed by burning the same year. The study was conducted on brushy NSR land in the Drier Maritime Coastal Western Hemlock biogeoclimatic subzone within the University of B.C. Research Forest at Haney. The study area used a randomized block design with 6 approximately one ha blocks, three of which were aerially sprayed with the herbicide-glyphosate in September 1987. The remaining three were sprayed in July 1988 then all blocks were burned in October, 1988 using a helicopter.

As the burn was carried out under less than optimum conditions when fuels were relatively moist, a uniformly low severity fire resulted. This did not help to discriminate between the two herbicide applications. Although there were few statistically significant differences between the two treatments in terms of their effects on fuels, soils, and vegetation, the general trend was that the 1987 herbicide application resulted in greater fuel consumption, nutrient loss, retardation of growth of competing vegetation, and first-year height growth of planted Douglas-fir seedlings. By the height of the first post-treatment growing season, there were no consistent trends among N, P and S, in the treatment-caused changes in ecosystem nutrient status, when comparing either ecosystems or treatments. Although it appears that browning one year in advance of burning is more effective than browning and burning the same year, this cannot yet be stated with certainty due to only relatively slight differences being found between the two treatments. However, it is feasible to broadcast burn herbicided areas in the CWHdm subzone the year after, as well as the same year as, herbicide application. The rapid regrowth of competing vegetation and uncertainty over the longer-term growth responses of the planted seedlings suggest that continued monitoring should occur in the area.

1.0 INTRODUCTION

Of British Columbia's estimated 824,000 ha of brushy site NSR land, approximately 59,000 ha lie within the Vancouver Forest Region (V.F.R.) (Otchere Boateng 1986). The significance of this region for brushy site NSR land increases when one considers that of the 49,000 ha added annually to this category of land, 18,000 ha comes from the V.F.R. If the existing NSR land were to be put back into timber production, the annual yield at culmination age would increase by 2,464,000 m^3 for B.C., and 385,000 m^3 for the V.F.R. This would result in an annual stumpage gain of $15.6 million for B.C. of which $3.3 million would come from the V.F.R. (Otchere Boateng 1986). More productive forests and higher stumpage values in the V.F.R. increase the importance of southern coastal B.C. forests beyond their areal extent and emphasize the importance of rehabilitating NSR lands within them.

With the signing of the Federal-Provincial Forestry Agreement (FRDA) for B.C., a major increase in site rehabilitation effort has occurred. A variety of mechanical, chemical, and burning rehabilitation treatments, either singly or in combination, are available. A number of studies have begun to compare the effectiveness of the different treatments and assess methods of optimizing the use of the different treatments and results are starting to be published.

One technique which is considered potentially useful for rehabilitating brushy sites dominated by deciduous tree and shrub species, is herbicide application followed by prescribed burning (hereafter referred to as "brown and burn") Although used increasingly, little is apparently known about the optimum way of applying the technique or about its long term effectiveness in coastal B.C. Although browning and burning and herbicide application have been studied in several of the existing FRDA studies in coastal B.C., none of these studies appear to have considered the optimum way of applying the brown and burn technique (Anon. 1986, Anon. 1987).

In a recent review of the literature available on the use of prescribed fire as a rehabilitation technique, Vihnanek and Feller (1984) found only one study of the brown and burn technique in B.C. - that of Lawson (1982) (with follow-up work by Marsh, 1983) and very few others elsewhere, although some extrapolation from slashburning studies is possible. Sutton (1985) has recently discussed the various treatments in a broad sense in a general discussion of vegetation management in Canada, while Carter *et al.*, (1978) have likewise discussed in a general way the

various treatments available in the U.S. However, there appears to be no published information and few, if any, studies on the optimum application, or effects on site productivity, of the brown and burn technique. This has been the major focus of the present study, which addresses the findings of Conard (1983) who, in a problem analysis of forest vegetation management in B.C. suggested that one of the highest priority research fields was the establishment of trials to evaluate the effects of different rehabilitation or vegetation management techniques on control of vegetation, and establishment and growth of crop trees.

Vision (glyphosate), a systemic herbicide, is the most commonly used herbicide in forestry in B.C. Vision is not a desiccant - it may be many weeks following spraying before mortality and browning of vegetation sufficient to allow fire spread occurs. Therefore, spraying has to be carried out early in the growing season if burning is to be carried out that same year. However, the efficacy of the herbicide in preventing resprouting may be higher for some species when applied later in the growing season. Also, it may not be possible to spray herbicides on some high elevation sites early in the growing season as meltwater may still be present on the site. Spraying glyphosate later in the growing season may optimize the efficacy of the herbicide, and allow a longer period for browning to occur.

2.0 OBJECTIVES OF THE STUDY

In light of the preceding discussion, a study was established with two main objectives:

1. To compare the effectiveness of two brown and burn treatments with respect to vegetative competition and growth of planted Douglas-fir seedlings, on an ecosystem-specific basis.
2. To quantify the effects of the two treatments on site nutrient status and soil fertility, on an ecosystem-specific basis.

The two treatments involve either browning one year followed by burning the next, or browning and burning the same year, using the herbicide - glyphosate. The study will determine which of the two treatments is more effective as a brushy site rehabilitation technique.

3. THE STUDY AREA

The study has taken place within the Marc watershed which lies within the University of B.C. Research Forest near Haney, approximately 40 km east of

Vancouver in southwestern B.C. This watershed has been studied by M. Feller and J.P. Kimmins since 1970 (e.g. Feller and Kimmins 1984). The watershed was once covered mainly with a 70 - 90-year-old western hemlock - western redcedar - Douglas-fir forest which was clearcut in 1973 then planted to Douglas-fir seedlings in April, 1975. Vigorous growth of competing species such as red alder, salmonberry, thimbleberry, bracken, salal, and maples, suppressed the planted seedlings to the extent that a survey in 1982 indicated a stocking rate of about 250 conifer stems/ha. The area was considered NSR and was given an aerial application of glyphosate which did not lead to any increase in stocking. In 1988, the area was still considered NSR and contained an approximately 6 ha block where the stocking was < 50 stems/ha.

The watershed lies within the Drier Maritime Coastal western Hemlock biogeoclimatic subzone of B.C. (Klinka *et al*, 1979). The area has a marine, warm to temperate, rainy climate with an average annual precipitation of 220 - 270 cm. Owing to the low elevation (140-300 m), snow falls only occasionally, and most precipitation (95%) is rain. Temperatures are mild, with an average daily mean of 17°C for the warmest month and 2°C for the coldest month.

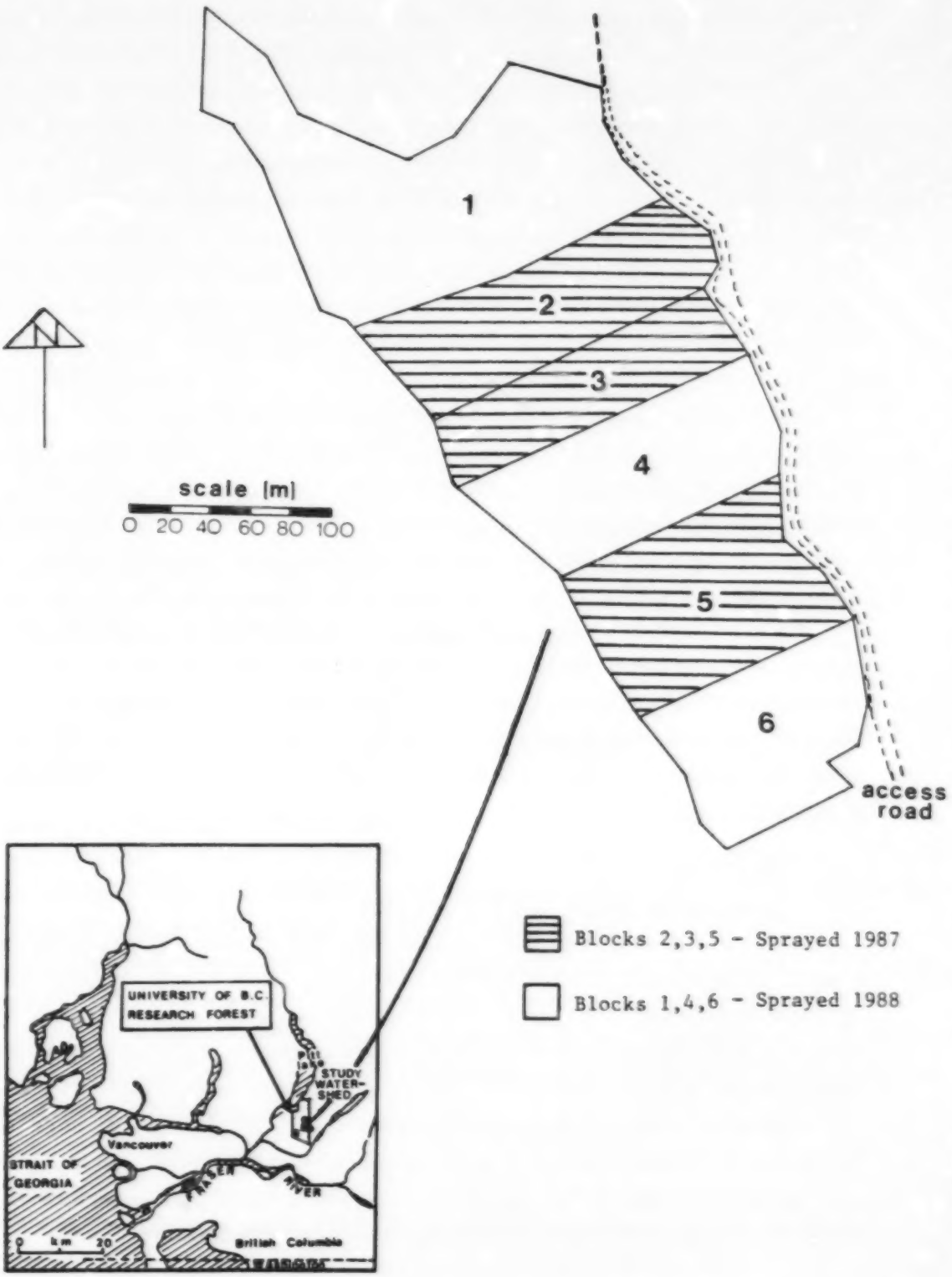
The bedrock consists predominantly of acid igneous rocks, mainly quartz diorite. The soils are of glacial origin and are primarily shallow, coarse-textured Humoferric Podzols (Canadian Soil Survey Committee 1978). Within the research plots, the mineral soil was overlain by a shallow (5-10 cm) moder-type of forest floor. The topography varies from flat to hilly with average slopes of 12-25% and a southwest aspect.

4.0 METHODS

4.1 Experimental Design - Field Operations

The area to be treated was subdivided into six adjacent approximately rectangular blocks each 0.6 to 1.6 ha in size (Figure 1). These blocks were delineated by trails constructed by bulldozer. Three of these blocks were randomly selected to receive a herbicide application (2.0 kg/ha active ingredient of glyphosate applied by helicopter) on 16 September, 1987. The remaining three blocks received a similar herbicide application (2.3 kg/ha active ingredient) on 7 July, 1988. All large trees on each of the blocks were cut down prior to herbicide application. All blocks were burned on 12 October, 1988. Ignition commenced at 12:40 p.m. and lasted 35 minutes. It was accomplished by helicopter using a strip back fire

Figure 1. Layout and location of the study area.



ignition pattern. The prevailing weather and Canadian Fire Weather Index (FWI) System codes and indices (Van Wagner 1987) for the burn, together with forest floor and woody fuel moisture contents at the time of the burn, are given in Table 1.

All blocks were planted with 2 + 1 bare root Douglas-fir seedlings (seedlot 1293) during May, 1989, at a 3.5 m spacing. Additional trees were planted in several clusters. These trees will be destructively sampled in the future for biomass and tree nutrient status measurements.

Each block was stratified into the two most common ecosystem types present - xeric (dry) and subhygric (moist) - based on topography and vegetation. All soil and vegetation measurements have been made separately on each of these two ecosystems. Consequently, the study is assessing the effects of two treatments (browning one year, burning the next vs. browning and burning the same year) on two ecosystems (xeric and subhygric or FdHw-Salal and Cw-Ladyfern site associations, respectively).

4.2 Field Measurements and Sampling

4.2.1 Characterization of the Burning Treatment

Weather conditions at the time of the burn and the FWI System codes and indices (Table 1) were determined from data collected by an on-site weather station installed at the beginning of the fire season.

The moisture contents of forest floor and woody materials were determined by destructive sampling immediately prior to the burn. Replicate (generally 12-19) samples of different forest floor layers or different size classes of dead woody fuels (Table 1) were collected, weighed immediately in the field using a portable electronic balance, then placed in labelled paper bags. Samples were later dried in an oven at 110°C and moisture contents calculated.

4.2.2 Impacts of the Treatments on Organic Materials

Organic material consumption by the burn was determined for each block by subtracting post-burn quantities of organic materials from pre-burn quantities. Organic materials were subdivided into 3 categories - living vegetation (vegetation that was relatively green and with a relatively high moisture content), dead woody material (slash and dead plant stems), and forest floor.

Table 1. Weather conditions, Fire Weather Index System codes and indices, and fuel moisture contents at the time of the burn in Marc watershed, 1300 hrs. on 12 October, 1988.

1. Weather T = 16.5 °C, RH = 70%, Wind = 1 km/hr from the S.W.

2. FWI codes and indices FFMC = 72, DMC = 10, DC = 192, ISI = 1.5, BUI = 18, FWI = 2

   All weather data were obtained from an on-site weather station. The FFMC was corrected for aspect and time of day according to tables in Alexander et al. (1984).

3. Fuel moisture contents (%)

Fuel type		Mean moisture content (standard deviation)		number of samples
Dead woody fuel				
≤1	cm diameter	25	(6)	15
1.1 - 3.0	" "	21	(2)	15
3.1 - 5.0	" "	22	(9)	15
5.1 - 7.0	" "	21	(6)	15
7.1 - 12.0	" "	20	(4)	15
>12	" "	22	(4)	14
Forest floor				
	L layer	72	(26)	18
0 - 2cm	F layer	124	(59)	19
2 - 4cm	F layer	158	(69)	12
4 - 6cm	F layer	152	(49)	6

Living vegetation mass was estimated by removing all such above-ground material from small (1 m^2) plots, using 10 randomly located plots per block before burning. The postburn mass of living vegetation was obtained by multiplying the preburn quantity by the percentage of the block remaining unburned after the fire since observations suggested that virtually all above-ground parts of vegetation in the burned area were killed by the fire.

The mass of dead woody material was estimated as follows:
Material > 1 cm in diameter was assessed using the line intersect technique (Van Wagner, 1968) and three randomly located equilateral triangles with 20 or 30 m sides per plot. The apexes of each triangle were permanently located in the plots using metal rods so that the same transects were traversed after the burn. The mass of materials was estimated by size class from measurements of relative densities, all preburn materials being separated into conifer or hardwood categories. Relative densities for the materials in the study area are given in Table 2.

Material ≤ 1 cm in diameter was assessed by destructive sampling of small (1 m^2) plots, using 10 randomly located plots per block, both before and immediately after burning.

Forest floor mass preburn was determined by destructive sampling of small plots (400 cm^2 surface area), using 5 plots per ecosystem type per block (10 plots per block). Postburn forest floor mass was estimated by multiplying the preburn mass for each ecosystem for each block by the proportion of the forest floor depth remaining after the burn, assuming that the forest floor bulk density was uniform with depth. Forest floor was sampled before and immediately after (for chemical analysis) burning.

Forest floor (LFH) depth of burn was determined using forest floor depth of burn pins, with 8 pins located systematically around the apex of each line intersect triangle (72 pins per block). Pins were classified as being in either xeric, subhygric or other sites so that forest floor depth of burn was determined for each ecosystem type for each block. This resulted in a total of 10-48 such measurements being made per ecosystem type per block. Preburn forest floor depth was measured at each depth of burn pin by measuring remaining forest floor depth after the burn, and adding this to depth of burn. Forest floor depth was again estimated the year after the burn (August 1989) using 20 randomly-located measurements per ecosystem per block.

Table 2. Relative densities for the different dead woody materials in the study blocks.

Size Class (cm)	Relative densities (kg/m^3)		
	Preburn		Postburn
	Conifer	Hardwood	
1.1 - 3.0	440 (80)	420 (90)	430 (40)
3.1 - 5.0	450 (40)	380 (80)	430 (50)
5.1 - 7.0	440 (30)	360 (80)	410 (40)
7.1 - 12.0	430 (40)	370 (50)	390 (20)
>12	400 (30)	n.p.	390 (50)

Standard deviations are given in parentheses
n = 8 for each relative density figure
n.p. = not present

4.2.3 Impacts of the Treatments on Soil Physical and Chemical Properties

The soil was split into two strata - the forest floor and the 0-20 cm layer of mineral soil. Ten samples of each stratum were collected from random locations and bulked to 5 samples for chemical analysis for each stratum for each ecosystem type for each block. Samples were collected during July-August, 1987 (pre-treatment) and during July-August, 1989 (first-year post-treatment). An additional 20 mineral soil samples were collected from each of the two ecosystem types during the pre-treatment 1987 sampling for coarse fragment content and bulk density analyses. The volume of each of these samples was determined in the field.

Mineral soil exposure was assessed before (July 1988), and the first year after (July 1989) burning along the transects of the triangles used for line intersect slash sampling.

4.2.4 Impacts of the Treatments on Vegetation

Understory vegetation biomass was determined prior to herbicide application (July 1987), prior to burning (August 1988) and at the height of the first post-treatment growing season (July 1989). Biomass was determined per ecosystem per block by destructively sampling 10 randomly located 1 m^2 plots per ecosystem type per block in 1987 and 1988, and 8 such plots in 1989. The understory vegetation was placed into 12 categories - *Salix* spp. (willows), other hardwood trees, *Gaultheria shallon* (salal), *Rubus* spp., *Vaccinium parvifolium* (red huckleberry), other shrubs, *Pteridium aquilinum* (bracken fern), other ferns, *Epilobium angusti-*

folium (fireweed), other herbs, grass, moss - for the 1989 sampling, but was not separated by category in 1987 and 1988.

Percent cover, by species, was recorded in July, 1987 and again in May, 1989, at the time of planting, using line transects, each 100 m long per ecosystem per block.

Tree growth measurement plots were selected; tree seedlings were staked and numbered, and had their heights measured at the time of planting and at the end of the first growing season (November, 1989). Each measurement plot is square or rectangular in shape and contains 60 trees. One such plot per ecosystem per block was established, giving a total of 720 staked and numbered trees.

Tree seedling biomass at the time of planting was not determined, but will be done during the coming year following the planned destructive sampling of seedlings for biomass and nutrient status determination.

4.2.5 Impacts of the Treatments on Ecosystem Nutrient Status

Nutrient quantities in the experimental blocks were estimated before burning (July 1988), immediately after burning (October 1988), and at the height of the first post-treatment growing season (August 1989). Nutrient quantities were estimated as follows:

Living understory vegetation - from measurements of the aboveground biomass of this (as described above) and its total nutrient concentrations, separated according to species (1989) and ecosystem (1988 and 1989).

Dead woody materials - from measurements of the mass of these materials (from line intersects for > 1 cm diameter materials and small plots for ≤ 1 cm diameter materials as described above) and their total nutrient concentrations, stratified by species and size class. Dead woody materials were not determined on an ecosystem-specific basis as it was assumed that their distribution was not influenced by ecosystem type. This assumption was supported by visual observation.

Forest floor - from measurements of forest floor mass (as described above) and its nutrient concentrations.

Mineral soil - for the 0-20 cm layer from measurements of its bulk density, coarse fragment content, and nutrient concentrations. Mineral soil was sampled as described above, only prior to treatment (July-August 1987) and during the first post-treatment year (July- August 1989).

Nutrient loss during the burn was determined for each ecosystem for each block by subtracting the postburn quantities of nutrients in living understory vegetation, dead woody materials, and forest floor, from the preburn quantities.

4.3 Laboratory Measurements

All plant material samples for dry mass analysis were oven-dried at 70°C prior to weighing. Subsamples for chemical analysis were ground to pass a 1 mm-mesh sieve. Plant material samples were analyzed for total N, P, K, Mg, and Ca using a Parkinson and Allen digestion (Parkinson and Allen 1975) followed by colorimetric analysis of NH_4 (N) and PO_4 (P) in solution using a Technicon TRAACS 800 continuous flow analysis (CFA) instrument, and atomic absorption spectrophotometric analysis of K, Mg, and Ca in solution using a Varian AA6 spectrophotometer. Total S analysis was also conducted, using a Fisher Model 475 Sulphur Analyzer.

Forest floor samples were also analyzed for organic matter - by the loss on ignition method (Page *et al.* 1982), mineralizable N - by an anaerobic incubation procedure modified from Waring and Bremner (1964), followed by analysis of NH_4 in solution using the Technicon TRAACS 800 CFA instrument, extractable P by Bray's method (Page *et al.* 1982) followed by analysis of the cations in solution using the Varian AA6 spectrophotometer, and pH in water using an Orion Model 404 specific ion meter with standard glass and silver/silver chloride reference electrodes.

Mineral soil samples for coarse fragment content and bulk density determination were oven-dried at 110°C then analyzed for coarse fragment content and bulk density by sieving and weighing (Page *et al.* 1982). Mineral soil samples for chemical analysis were air-dried and sieved prior to analysis. Analyses were conducted on the < 2 mm fraction. Results were expressed on an oven-dry basis by oven-drying subsamples at 110°C to determine their moisture content, then correcting soil masses used in analyses for this water content. Mineral soil samples were analyzed for:

- total N by Kjeldahl digestion (Page *et al.*, 1982) followed by analysis of NH_4 in solution using the TRAACS 800 CFA instrument, and
- total C, mineralizable N, extractable P, extractable K, Mg, and Ca, pH in water, and total S using the methods described above for forest floor analyses.

4.4 Data Analysis

Comparison of the effects of the two treatments on fuels, soil properties, and vegetation, on an ecosystem-specific basis, was done using analysis of variance when possible. The assumption of normality could not be tested due to the limited number of data points, but the assumption of homogeneity of variances was tested using Bartlett's test. When variances were not homogeneous, since group sample sizes were equal and heterogeneity was not too great, the analysis of variance results were still accepted (Zar 1984). Significant group means were distinguished, when necessary, using Tukey's HSD multiple-comparison test. All statistical analyses were conducted using SYSTAT on a microcomputer (Wilkinson 1988).

5.0 RESULTS AND DISCUSSION

5.1 Characterization of the Burning Treatment

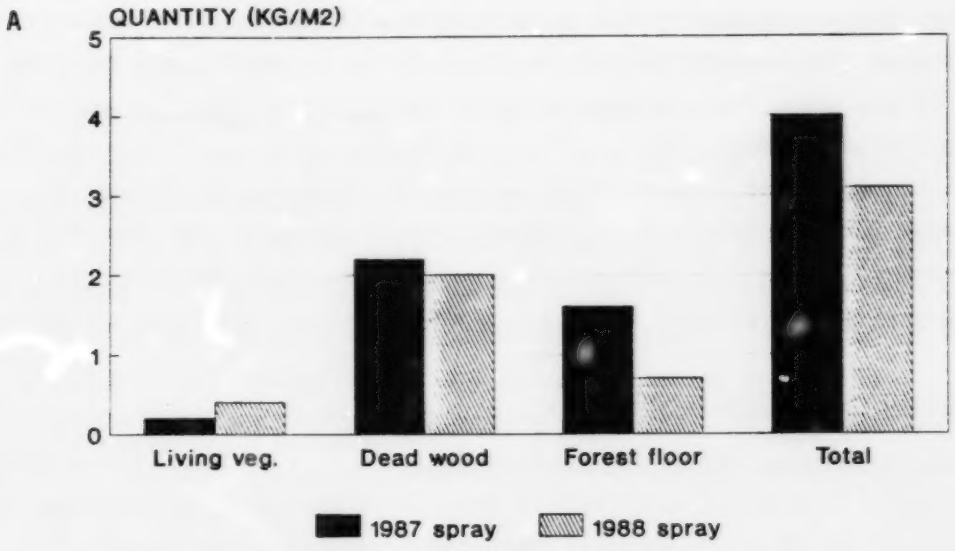
The FWI System codes and indices of the day of the burn (Table 1) suggested that a low severity fire would result. Unfortunately, the burn was not able to be conducted earlier when conditions would have favoured a higher severity burn. The day it was conducted, 12 October, 1988, was the last possible day in 1988 for a reasonable prescribed burn in the study area. The feeling that this was likely the case resulted in the burn being conducted under less than optimum conditions (moderate severity burn). For the prevailing conditions, the Prescribed Fire Predictor (Muraro 1975) impact rank was 1.

5.2 Impacts of the Treatments on Organic Materials

The percentage of area burned was generally greater for xeric than for subhygric ecosystems, and for the 1987 herbicide application than for the 1988 application (Table 3). However, these differences were statistically significant only in the case of the different application times and xeric ecosystems.

Preburn mass, postburn mass, and consumption of living vegetation, dead woody material, and forest floor for each of the 6 experimental blocks are given in Table 4. Absolute and percent consumption for the two treatments are compared in Figure 2. Prior to burning, relatively little living vegetation ($\leq$0 .7 kg/m^2) was present so its consumption contributed relatively little to the total fuel consumption (<15% of the total for all blocks except for block 4 where it was 22%). Dead woody material comprised most (63-75%) of the preburn fuel and accounted for most (54%-80%) of the consumption.

Figure 2. Absolute (A) and percent (B) fuel consumption during the slashburn in the study area, by herbicide application treatment.



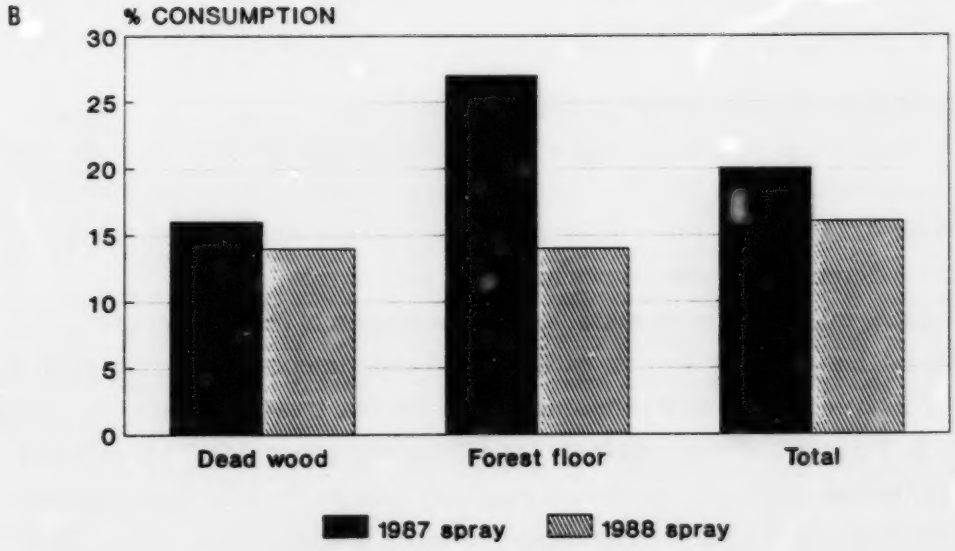


Table 3. Percentage of area burned, by ecosystem and experimental block, by the burn in Marc Watershed.

Block	Ecosystem type	
	Xeric	Subhygric
1	73	50
2	86	76
3	94	80
4	53	52
5	71	70
6	66	80
'87 spray area (blocks 2,3,5)	84[a]	75[ab]
'88 spray area (blocks 1,4,6)	64[b]	61[b]
entire area	74	68

For the '87 and '88 spray area, numbers followed by different letters are significantly different at $P<0.10$, comparing both between ecosystems and spray treatments.

Dead woody material was neither quantified on an ecosystem-specific basis, nor determined from replicate measurements, so the ecosystem-specific effect of the two treatments cannot be determined. However, t tests indicated that treatment type had no significant effect on the absolute or percentage consumption of any size class of material although these values were slightly greater for the 1987 herbicide application for total dead woody material.

Preburn forest floor masses were generally slightly greater, but not significantly so, in the xeric ecosystems (Table 5). Forest floor consumption, in both absolute and percentage terms, was greater in the xeric than in the subhygric ecosystem (Table 5), but none of the differences were statistically significant. Consumption, both absolute and percent, was also greater in the 1987 herbicide application area, compared to the 1988 area, but the differences between the two were, again, not statistically significant. The lack of statistically significant differences can be attributed partly to the low severity burn and partly to the high variability in forest floor mass, which is reflected in the relatively high standard deviations. The relatively low forest floor consumption in blocks 4 and 6 might have been due to the fact that these two blocks had the greatest quantities of living veg-

Table 4. Organic material before and after the burn, and consumption in the burned areas within the study blocks during the burn in Marc watershed. All data are in kg/m².

Block		Living vegetation	Dead woody material - diameter class							Forest floor
			≤1cm	1.1-3.0cm	3.1-5.0cm	5.1-7.0cm	7.1-12.0cm	>12cm	Total	
1-	before	0.3	0.5	0.2	0.2	0.3	0.9	7.1	9.2	5.2
	after	0.0	0.1	0.1	0.3	0.3	0.7	5.5	7.0	3.7
	consumption	0.3	0.4	0.1	(0.0)	0.0	0.2	1.6	2.2	1.6
2-	before	0.2	0.6	0.3	0.4	0.3	1.0	17.4	20.0	6.6
	after	0.0	0.0	0.2	0.3	0.4	0.7	15.5	17.1	4.3
	consumption	0.2	0.5	0.1	0.1	(0.0)	0.3	1.9	2.9	2.2
3-	before	0.1	0.4	0.3	0.3	0.4	1.1	10.5	12.9	3.8
	after	0.0	0.1	0.3	0.3	0.4	0.8	8.1	9.9	2.6
	consumption	0.1	0.3	0.0	0.0	0.1	0.3	2.4	3.1	1.3
4-	before	0.7	0.7	0.3	0.4	0.3	0.9	15.3	17.8	3.8
	after	0.0	0.1	0.3	0.3	0.3	0.7	13.8	15.4	3.7
	consumption	0.7	0.6	0.0	0.0	0.1	0.2	1.5	2.4	0.1
5-	before	0.2	0.4	0.2	0.2	0.2	0.9	9.0	10.8	7.7
	after	0.0	0.0	0.2	0.2	0.1	0.6	7.8	9.0	6.3
	consumption	0.2	0.4	0.0	0.0	0.1	0.2	1.2	1.9	1.4
6-	before	0.4	0.5	0.2	0.3	0.3	1.0	16.3	18.5	5.6
	after	0.0	0.1	0.2	0.3	0.2	0.8	14.2	15.7	5.3
	consumption	0.4	0.5	0.0	0.0	0.0	0.2	2.1	2.8	0.3
'87 spray area (blocks 2,3,5)										
	before	0.2	0.4	0.3	0.3	0.3	1.0	12.3	14.1	6.0
	after	0.0	0.1	0.2	0.3	0.3	0.7	10.4	11.9	4.4
	consumption	0.2	0.4	0.0	0.1	0.0	0.3	1.8	2.2	1.6
'88 spray area (blocks 1,4,6)										
	before	0.4	0.6	0.2	0.3	0.3	0.9	12.9	14.6	4.9
	after	0.0	0.1	0.2	0.3	0.3	0.7	11.2	12.6	4.2
	consumption	0.4	0.5	0.0	0.0	0.0	0.2	1.7	2.0	0.7
Entire burned area										
	before	0.3	0.5	0.2	0.3	0.3	1.0	12.6	14.4	5.5
	after	0.0	0.1	0.2	0.3	0.3	0.7	10.8	12.3	4.3
	consumption	0.3	0.4	0.0	0.0	0.0	0.2	1.8	2.1	1.2

Note:
1. Discrepancies in totals or differences between before- and after-burn values (consumption) are due to rounding errors.
2. Numbers in parentheses represent increases after the burn.

Table 5. Preburn forest floor mass and consumption (kg/m^2) during the burn in Marc watershed.

Block/Ecosystem	Xeric				Subhygric			
	Preburn	Consumption			Preburn	Consumption		
	mass	absolute	%		mass	absolute	%	
1	5.30 (2.04)	1.59 (0.81)	30	(15)	4.35 (1.69)	1.20 (0.75)	28	(18)
2	6.70 (4.25)	2.38 (1.87)	36	(28)	5.33 (3.94)	0.94 (1.65)	18	(32)
3	3.80 (1.60)	1.29 (0.71)	34	(19)	4.26 (1.96)	0.99 (1.06)	23	(25)
4	3.71 (1.73)	0.13 (0.75)	4	(23)	4.61 (2.36)	0.32 (1.06)	7	(23)
5	8.12 (4.02)	1.49 (2.08)	18	(25)	4.36 (2.22)	0.79 (0.89)	18	(20)
6	5.54 (2.31)	0.31 (1.56)	6	(30)	6.31 (3.08)	0.15 (1.93)	2	(26)
'87 spray (blocks 2,3,5)	6.20 (3.50)	1.72 (1.67)	29	(28)	4.65 (2.85)	0.91 (1.24)	20	(27)
'88 spray (blocks 1,4,6)	4.85 (2.04)	0.68 (1.10)	13	(21)	5.09 (2.44)	0.56 (1.34)	12	(29)
entire area	5.53 (2.87)	1.20 (1.41)	21	(25)	4.87 (2.65)	0.73 (1.29)	16	(28)

Standard deviations are in parentheses

Table 6. Preburn forest floor depth and depth of burn (cm) caused by the burn in Marc watershed.

Blocks Ecosystem Type	Xeric			Subhygric		
	forest floor depth	depth of burn	N	forest floor depth	depth of burn	N
1	7.0 (2.7)	2.1 (2.2)	24	5.8 (2.6)	1.6 (1.6)	48
2	9.3 (5.9)	3.3 (4.2)	32	7.4 (5.3)	1.3 (1.7)	30
3	5.0 (2.1)	1.7 (2.3)	27	5.6 (4.4)	1.3 (2.1)	32
4	5.8 (2.7)	0.2 (0.4)	24	7.2 (3.6)	0.5 (0.8)	40
5	8.2 (5.1)	1.5 (2.1)	37	4.4 (2.4)	0.8 (0.9)	24
6	7.2 (4.9)	0.4 (1.2)	10	8.2 (7.3)	0.2 (0.4)	20
'87 spray (blocks 2,3,5)	7.7 (4.5)	2.2 (2.9)	96	5.9 (4.2)	1.2 (1.6)	86
'88 spray (blocks 1,4,6)	6.5 (3.1)	1.0 (1.3)	58	6.8 (3.9)	0.9(1.1)	108
entire area	7.3 (4.0)	1.8 (2.3)	154	6.4 (4.0)	1.0 (1.3)	194

Standard deviations are in parentheses.
N = number of depth of burn measurements

etation at the time of the burn (Table 4). Such vegetation might have sheltered the forest floor and maintained relatively high humidities near the ground surface, retarding forest floor drying and leading to higher forest floor moisture contents at the time of the burn. A similar trend in dead woody material consumption (percent consumption was lowest in block 4 and second lowest in blocks 6 and 2) is consistent with higher fuel moisture in blocks 4 and 6 at the time of the burn. However, other factors such as ignition pattern in relation to fuel continuity (i.e. poorer ignition in blocks 4 and 6) cannot be ruled out.

Preburn forest floor depths varied from 5 to 10 cm in the xeric ecosystems, and 4 to 9 cm in the subhygric ones, although there were no significant differences between ecosystems (Table 6). Depths of burn were generally greater for the xeric than the subhygric ecosystems and for the 1987 herbicide application areas compared to the 1988 areas (Table 6), although none of these differences were statistically significant.

In summary, all the data on the impacts of the burn on organic matter are consistent with the impacts being greater on the xeric ecosystem than on the subhygric one, which would be predicted by the relative moisture contents of the forest floors and lower slash fuels of the two ecosystems. The data are also all consistent with greater impacts and fuel consumption occurring for the 1987 herbicide application, compared to the 1988 application. However, the general lack of statistical significance of the differences between treatments or ecosystems, which can be attributed at least partly to the application of a relatively low severity burn, precludes a definitive conclusion at this stage.

Based on a) the fact that the burn, low severity that it was, still accomplished silvicultural objectives in terms of creation of plantable spots, and b) observations of vegetation condition during the 1988 growing season, it is felt that -

1) the areas sprayed in September 1987 could have been burned the following spring (dead bracken from the previous 1987 growing season would have provided a good source of fine fuel in spring 1988 and relatively little renewed growth of vegetation occurred); and
2) the areas sprayed in July 1988 could have been burned under relatively dry conditions (DMC > 30, DC > 250) in early September 1988.

5.3 Impacts of the Treatments on Soil Properties

Mineral soil exposure was low prior to burning ($\leq$0.5% in all ecosystems in all blocks -- Table 7), and increased slightly but significantly ($P<0.05$) to 0.2 - 6.2%

Table 7. Mineral soil exposure (%) in the experimental blocks before and the year after the burn in Marc watershed.

Block/Ecosystem	Xeric		Subhygric	
	Preburn (1988)	August 1989	Preburn (1988)	August 1989
1	0.2	3.7	0.1	2.1
2	0.5	6.2	0.0	0.3
3	0.2	3.3	0.2	4.4
4	0.2	1.4	0.0	1.2
5	0.1	2.5	0.0	0.8
6	0.1	2.3	0.0	0.2
'87 spray area (blocks 2,3,5)	0.3	4.0	0.1	1.8
'88 spray area (blocks 1,4,6)	0.2	2.5	0.1	1.2
entire area	0.2	3.2	0.1	1.5

by the summer following the burn. Mineral soil exposure tended to be greater in the 1987 herbicide application area than in the 1988 area. However, none of the differences between ecosystems or between herbicide treatments were statistically significant.

Mineral soil bulk density and coarse fragment content were not expected to be affected by the treatments so they were measured only prior to burning. The data obtained (Appendix I) were used to calculate quantities of nutrients in the mineral soil.

The soil was separated into two components -- forest floor and mineral soil -- for the purpose of chemical analysis. Concentrations and quantities of nutrients and other chemical parameters in the forest floor are summarized in Tables 8 and 9, respectively. Statistical analysis of these data (Table 10) indicates that there were no significant differences for any chemical parameter between the herbicide application treatments and only one significant difference (total P concentrations were higher in xeric than subhygric ecosystems) between ecosystems. There were many significant differences between sampling times (Table 10) with all nutrient quantities, and total N, total K, organic matter, and extractable K, Mg, and Ca concentrations being lower in 1989 than before treatment.

Within the mineral soil, ecosystem type had a more pronounced effect on chemical concentrations and quantities (Table 11 - 13) but herbicide application time, again, had little significant effect on chemical concentrations and none on quantities.

Table 8. Chemical concentrations and pH values in the forest floors in the study blocks in Marc watershed, averaged by ecosystem, treatment, and year of sampling.

Ecosystem/ treatment	Total (%)							Mineralizable (ppm)	Extractable (ppm)				
	N	P	K	Mg	Ca	S	organic matter	N	P	K	Mg	Ca	pH
1) Comparison between ecosystems and sampling times													
Pretreatment - 1988													
Xeric	0.981(0.185)	0.067(0.009)	0.117(0.020)	0.093(0.014)	0.494(0.084)	0.156(0.009)	85(4)	116.6 (31.9)	86.2 (16.9)	179.1 (26.4)	441.6 (62.9)	4600.1(553.7)	4.4(0.2)
Subhygric	1.055(0.151)	0.046(0.004)	0.122(0.013)	0.098(0.017)	0.495(0.078)	0.141(0.030)	86(8)	122.0 (30.7)	83.7 (17.0)	179.1 (28.7)	425.2 (52.8)	4774.8(643.7)	4.6(0.3)
First postburn year - 1989													
Xeric	0.814(0.093)	0.060(0.007)	0.100(0.013)	0.104(0.020)	0.542(0.061)	0.114(0.030)	63(8)	103.6 (15.6)	79.4 (12.6)	128.8 (21.0)	362.4 (44.8)	3370.6(684.7)	4.5(0.2)
Subhygric	0.972(0.123)	0.044(0.004)	0.104(0.013)	0.108(0.021)	0.530(0.056)	0.104(0.017)	66(7)	110.1 (28.6)	73.5 (14.4)	125.6 (23.0)	389.0 (44.9)	3930.3(326.8)	4.6(0.1)
2) Comparison between treatments													
Pretreatment - 1988													
'87 spray	0.987(0.142)	0.056(0.005)	0.121(0.011)	0.084(0.013)	0.512(0.078)	0.136(0.024)	84(6)	113.9 (27.2)	87.9 (15.0)	190.2 (27.1)	407.5 (66.4)	4673.7(590.3)	4.4(0.2)
'88 spray	1.049(0.192)	0.057(0.010)	0.119(0.021)	0.106(0.018)	0.477(0.084)	0.161(0.030)	87(6)	124.7 (35.0)	81.9 (18.7)	168.0 (28.1)	459.3 (48.3)	4701.2(610.3)	4.7(0.2)
First postburn year - 1989													
'87 spray	0.912(0.079)	0.053(0.006)	0.099(0.012)	0.103(0.023)	0.532(0.069)	0.109(0.025)	64(7)	101.6 (14.6)	73.7 (8.7)	119.2 (20.6)	365.8 (48.0)	3612.8(607.5)	4.6(0.2)
'88 spray	0.874(0.132)	0.051(0.006)	0.106(0.014)	0.109(0.017)	0.540(0.046)	0.109(0.025)	65(8)	112.1 (29.1)	79.2 (17.1)	135.3 (23.4)	385.6 (41.6)	3688.1(454.5)	4.5(0.1)

Standard deviations are in parentheses

Table 9. Nutrient quantities (kg/ha) in the forest floors in the study blocks in Marc watershed, averaged by ecosystem, treatment, and year of sampling.

Ecosystem/	Total						Mineralizable	Extractable			
treatment	N	P	K	Mg	Ca	S	N	P	K	Mg	Ca
1) **Comparison between ecosystems and sampling times**											
Pretreatment - 1988											
Xeric	542(154)	37(9)	65(18)	51(13)	273(74)	86(19)	6 (2)	5(1)	10(3)	24(6)	254(62)
Subhygric	514(136)	22(5)	59(14)	48(13)	241(65)	69(21)	6 (2)	4(1)	9(2)	21(5)	232(60)
First postburn year - 1989											
Xeric	290(112)	21(8)	36(14)	37(15)	193(74)	41(19)	4(2)	3(1)	5(2)	13(5)	120(51)
Subhygric	319(127)	14(5)	34(13)	36(15)	174(68)	34(14)	4(2)	2(1)	4(2)	13(5)	129(50)
2) **Comparison between treatments**											
Pretreatment - 1988											
'87 spray	536(150)	30(8)	66(17)	46(13)	278(79)	74(22)	6(2)	5(1)	10(3)	22(6)	254(69)
'88 spray	522(136)	28(7)	59(15)	53(13)	237(60)	80(21)	6(2)	5(1)	10(2)	23(5)	234(53)
First postburn year - 1989											
'87 spray	307(122)	18(7)	33(13)	35(16)	179(74)	37(17)	3(1)	2(1)	4(2)	12(5)	121(51)
'88 spray	305(118)	18(7)	37(14)	38(15)	188(69)	38(16)	4(2)	3(1)	5(2)	13(5)	128(48)

Standard deviations are in parentheses

Table 10. Significance of the effects of treatment, ecosystem, and year of sampling on forest floor nutrient concentrations and quantities, and pH values.

a) Concentrations

Comparison	Total						Mineralizable	Extractable					
	N	P	K	Mg	Ca	S	organic matter	N	P	K	Mg	Ca	pH
Treatment (TRT)	-	-	-	-	-	-	-	-	-	-	-	-	-
Ecosystem (ECO)	-	*	-	-	-	-	-	-	-	-	-	-	-
Year (YR)	*	-	*	-	-	-	*	-	-	*	*	*	-
TRT x ECO	-	-	-	-	-	-	-	-	-	-	-	-	-
TRT x YR	*	-	-	-	-	-	-	-	-	*	-	-	-
ECO x YR	-	-	-	-	-	-	-	-	-	-	*	-	-
TRT x ECO x YR	-	-	-	-	-	-	-	-	-	-	-	-	-

b) Quantities

	Total						Mineralizable	Extractable			
	N	P	K	Mg	Ca	S	N	P	K	Mg	Ca
Treatment	-	-	-	-	-	-	-	-	-	-	-
Ecosystem	-	-	-	-	-	-	-	-	-	-	-
Year	*	*	*	*	*	*	*	*	*	*	*
TRT x ECO	-	-	-	-	-	-	-	-	-	-	*
TRT x YR	-	-	*	-	*	-	-	-	-	-	-
ECO x YR	-	-	-	-	-	-	-	-	-	-	-
TRT x ECO x YR	-	-	-	-	-	-	-	-	-	-	-

Results are from analyses of variance
* indicates a significant effect at $P<0.05$

Table 11. Chemical concentrations and pH values in the surface 20 cm of mineral soil in the study area in Marc watershed, averaged by ecosystem, treatment, and year of sampling.

Ecosystem/ treatment	Total N (%)	Mineralizable N (ppm)	Total P (%)	Extractable P (ppm)	Extractable K (ppm)	Extractable Mg (ppm)	Extractable Ca (ppm)	Total S (%)	Organic matter r(%)	pH
1) Comparison between ecosystems and sampling times										
Pretreatment - 1987										
Xeric	0.187 (0.037)	9.1 (7.5)	0.053 (0.014)	43.0 (11.4)	44.8 (17.8)	21.3 (13.3)	133.6 (58.2)	0.028 (0.011)	13 (3)	4.5 (0.3)
Subhygric	0.257 (0.076)	17.7 (11.9)	0.064 (0.011)	32.1 (7.0)	45.8 (14.2)	32.1 (18.0)	387.0 (160.5)	0.036 (0.011)	16 (5)	4.7 (0.3)
First year post-treatment - 1989										
Xeric	0.194 (0.050)	11.8 (7.3)	0.058 (0.028)	43.2 (17.5)	35.0 (8.9)	25.0 (13.6)	151.9 (80.0)	0.022 (0.007)	11 (4)	4.8 (0.4)
Subhygric	0.270 (0.075)	28.9 (22.5)	0.065 (0.031)	30.9.(10.2)	29.7 (12.0)	35.1 (14.4)	433.8 (156.5)	0.028 (0.007)	14 (5)	5.2 (0.3)
2) Comparison between treatments										
Pretreatment - 1987										
'87 spray	0.228 (0.040)	13.0 (5.7)	0.060 (0.009)	38.8 (6.8)	45.2 (12.6)	29.1 (12.3)	274.9 (88.9)	0.033 (0.008)	15 (3)	4.5 (0.3)
'88 spray	0.217.(0.045)	13.8 (8.4)	0.056 (0.008)	36.3 (6.6)	45.4 (10.3)	24.4 (9.4)	245.8 (82.8)	0.031 (0.008)	14 (3)	4.7 (0.2)
First year post-treatment - 1989										
'87 spray	0.222 (0.043)	17.7 (10.2)	0.067 (0.022)	34.1 (10.1)	29.0 (6.8)	31.1 (9.9)	312.1 (101.6)	0.027 (0.006)	13 (3)	5.1 (0.3)
'88 spray	0.242 (0.043)	23.0 (12.0)	0.057 (0.019)	39.9 (9.8)	35.7 (6.2)	28.9 (9.7)	273.6 (72.1)	0.023 (0.003)	13 (3)	4.9 (0.2)

Standard deviations are in parentheses
n = 30 for each value

Table 12. Nutrient quantities (kg/ha) in the surface 20 cm of mineral soil in the study area in Marc watershed, averaged by ecosystem, treatment, and year of sampling.

Ecosystem/ treatment	Total N	Mineralizable N	Total P	Extractable P	Extractable K	Extractable Mg	Extractable Ca	Total S
1) **Comparison between ecosystems and sampling times**								
Pretreatment - 1988								
Xeric	1870 (550)	9 (8)	530 (170)	43(15)	45(21)	21(14)	130 (70)	280 (130)
Subhygric	2620(1090)	18(13)	650 (150)	33(12)	47(20)	33(21)	400 (200)	370 (160)
First year post-treatment - 1989								
Xeric	1940 (680)	12 (8)	580 (310)	43(20)	35(12)	25(15)	150 (90)	220 (90)
Subhygric	2750(1110)	29(24)	660 (370)	32(14)	30(15)	36(18)	440 (200)	290 (110)
2) **Comparison between treatments**								
Pretreatment - 1988								
'87 spray	2300 (610)	13 (6)	610 (120)	39(10)	46(16)	30(14)	280 (110)	330 (100)
'88 spray	2190 (620)	14 (9)	570 (110)	37 (9)	46(13)	25(11)	250 (100)	310 (100)
First year post-treatment - 1989								
'87 spray	2250 (620)	18(11)	670 (260)	35(12)	30 (9)	31(11)	310 (130)	270 (80)
'88 spray	2460 (660)	23(14)	570 (220)	40(13)	36 (9)	30(12)	280 (100)	240 (50)

Standard deviations are in parentheses
n = 30 for each value

Table 13. Significance of the effects of treatment, ecosystem, and year of sampling on the surface (20cm) mineral soil nutrient concentrations and quantities and pH values.

a) Concentrations

Comparison	Total N	Mineral-izable N	Total P	Extractable P	Extractable K	Extractable Mg	Extractable Ca	Total S	organic matter	pH
Treatment (TRT)	-	-	*	-	-	-	-	-	-	-
Ecosystem (ECO)	*	*	-	*	-	*	*	*	*	*
Year (YR)	-	*	*	-	*	-	-	*	*	*
TRT X ECO	-	*	-	-	-	*	-	-	-	-
TRT X YR	-	-	-	-	-	-	-	-	-	*
ECO X YR	-	-	-	-	*	-	-	-	-	-
TRT X ECO X YR	*	*	-	-	-	-	-	-	-	-

b) Quantities

Comparison	Total N	Mineralizable N	Total P	Extractable P	Extractable K	Extractable Mg	Extractable Ca	Total S
Treatment	-	-	-	-	-	-	-	-
Ecosystem	*	*	-	*	-	*	*	*
Year	-	*	*	-	*	-	-	*
TRT X ECO	-	*	-	-	-	*	-	-
TRT X YR	-	-	-	-	-	-	-	-
ECO X YR	-	-	-	*	-	-	-	-
TRT X ECO X YR	*	*	-	-	-	-	-	-

Results are from analyses of variance
* indicates a significant effect at $P<0.05$

The subhygric mineral soil tended to have significantly higher N, Mg, Ca, S, and organic matter concentrations, and pH values than the xeric mineral soil, both before and after the brown and burn treatments.

The year following the burn, mineral soil mineralizable N and total P concentrations, and pH were higher, and extractable K, total S, and organic matter concentrations were lower than before treatment (Tables 11 and 13). Several interactions, however, complicate interpretation of the results (Table 13). Mineral soil quantities (Tables 12 and 13) displayed almost identical trends to concentra

tions, which was expected since mineral soil bulk density was assumed not to vary between blocks or over time.

The fact that ecosystem had a more pronounced effect on mineral soil than on forest floor nutrient status can be attributed to the recent management history of the study area. The forest floors were relatively young, having developed after clearcutting in 1974 and a herbicide application in 1982. As such, they are unlikely to be in equilibrium with their environment. The mineral soils, on the other hand, have developed over thousands of years and, while they may have been affected by the recent management of the area, are still likely to reflect their environment to some extent.

Neither forest floor nor mineral soil nutrient status differed to any great extent between the two herbicide treatments. This was expected, given the relatively mild nature of the burn and the fact that organic matter losses did not differ greatly between the two brown and burn treatments. The lower the severity of a fire, the lower is likely to be its impact on soils (Feller, 1982).

When nutrient quantities in the entire soil (i.e. forest floor plus mineral soil combined) are considered, it can again be seen that there were no significant differences between treatments (Tables 14 and 15). There were, however, significantly greater quantities of N, Mg, Ca, and S, and lower quantities of extractable P in the subhygric ecosystem than in the xeric ecosystem soils. The net result of the treatments was to significantly decrease K, Ca, and S quantities in the soil, the year after the burn (Tables 14 and 15). Total N quantities appeared to be decreased, and mineralizable N quantities increased, by the treatments, but these changes were not statistically significant.

5.4 Impacts of the Treatments on Ecosystem Nutrient Status

Nutrient losses from the ecosystem as a result of the treatments may have occurred through leaching through the soil or through volatilization and particulate losses to the atmosphere during the burn. Of these, atmospheric losses tend to greatly outweigh leaching losses (e.g. Feller and Kimmins 1984).

Atmospheric losses were estimated by comparing pre- and post-burn nutrient quantities in organic material above the mineral soil surface (Appendix II). The relatively low severity fire, which consumed only around 3 kg/m^2 of organic material, and only the surface 1 - 2 cm forest floor, was not expected to cause

Table 14. Total nutrient content of forest floor and mineral soil in the study blocks in Marc watershed, averaged by ecosystem, treatment, and year of sampling.

Ecosystem/ treatment	Total N	Mineralizable N	Total P	Extractable P	Extractable K	Extractable Mg	Extractable Ca	Total S
1) **Comparison between ecosystems and sampling times**								
Pretreatment - 1988								
Xeric (130)	2410(570)	15 (8)	570(170)	48(15)	55(21)	45(15)	380(90)	370
Subhygric (160)	3130(1100)	24(13)	670(150)	37(12)	56(20)	54(22)	630(210)	440
First year post-treatment - 1989								
Xeric (90)	2230(690)	16 (8)	600(310)	46(20)	40(12)	38(16)	270(100)	260
Subhygric (110)	3070(1120)	33(24)	670(370)	34(14)	34(15)	49(19)	570(210)	320
2) **Comparison between treatments**								
Pretreatment - 1988								
'87 spray (100)	2840(630)	19 (6)	640(120)	44(10)	56(16)	52(15)	530(130)	400
'88 spray (100)	2710(630)	20 (9)	600(110)	41 (9)	54(13)	48(12)	480(110)	390
First year post-treatment - 1989								
'87 spray (80)	2560(630)	21(11)	690(260)	37(12)	34 (9)	43(12)	430(140)	310
'88 spray (50)	2770(670)	27(16)	590(220)	43(13)	41 (9)	43(13)	410(110)	280

Standard deviations are in parentheses

Table 15. Significance of the effects of treatment, ecosystem, and year of sampling on nutrient quantities in forest floor and mineral soil combined.

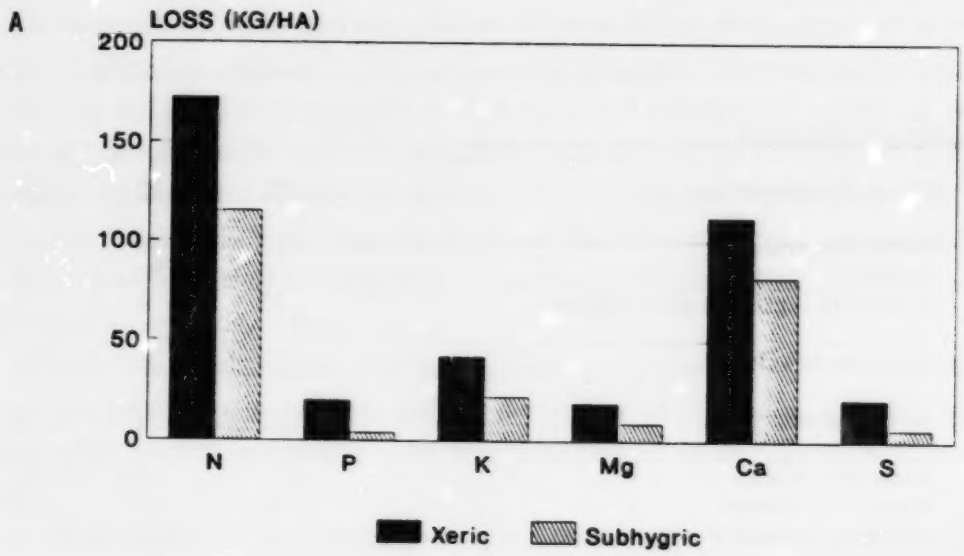
Comparison	Total N	izable N	Mineral- Total P	Extractable P	K	Mg	Ca	S	Total
Treatment (TRT)	-	-	-	-	-	-	-	-	
Ecosystem (ECO)	*	*	-	*	-	*	*	*	
Year (YR)	-	-	-	-	*	-	*	*	
TRT X ECO	-	*	-	-	-	*	-	-	
TRT X YR	-	-	-	-	-	-	-	-	
ECO X YR	-	-	-	-	-	-	-	-	
TRT X ECO X YR	-	*	-	-	-	-	-	-	

Results are from analyses of variance
*indicates a significant effect at $P<0.05$

large nutrient losses (cf. Feller 1990). The estimated losses (Appendix III, Figure 3) are relatively low for coastal B.C. slashburns (cf. Feller 1990) but generally lie within the 95% confidence band around the regression lines for Coastal Western Hemlock zone slashburns which give nutrient loss as a function of forest floor depth of burn (Feller 1990). Losses were generally less from the moister subhygric ecosystem than from the xeric ecosystem. Losses were less, in the case of N, P, K, and Ca, but greater in the case of Mg and S, from the 1988 herbicide application than from the 1987 application (Figure 3). However, all differences between the two treatments, except those for N and Ca, were relatively slight. Due to the way in which the loss estimates were made, it is not considered meaningful to conduct statistical analysis of the differences between treatments or ecosystems.

Nutrient losses occurred during the burn, so it is of interest to examine the nutrient status of the ecosystems affected by the treatments, the year after (1989). This could be done for N, P, and S, the three nutrients for which total mineral soil quantities could be estimated. Comparing the two ecosystems, the greater N losses during the burn from the xeric ecosystem, appeared to be reflected by greater net N decreases in this ecosystem, although the net decreases were not as great as the losses during the burn for both ecosystems (decreases of 159 and 39 kg/ha vs losses of 172 and 115 kg/ha for the xeric and subhygric ecosystems, respectively (Table 16). Losses from the forest floor were partly offset by gains in the mineral soil and in living vegetation. During the first year following treatment, understory

Figure 3. Nutrient loss to the atmosphere during the slashburn in the study area by ecosystem type (A) and herbicide application treatment (B).



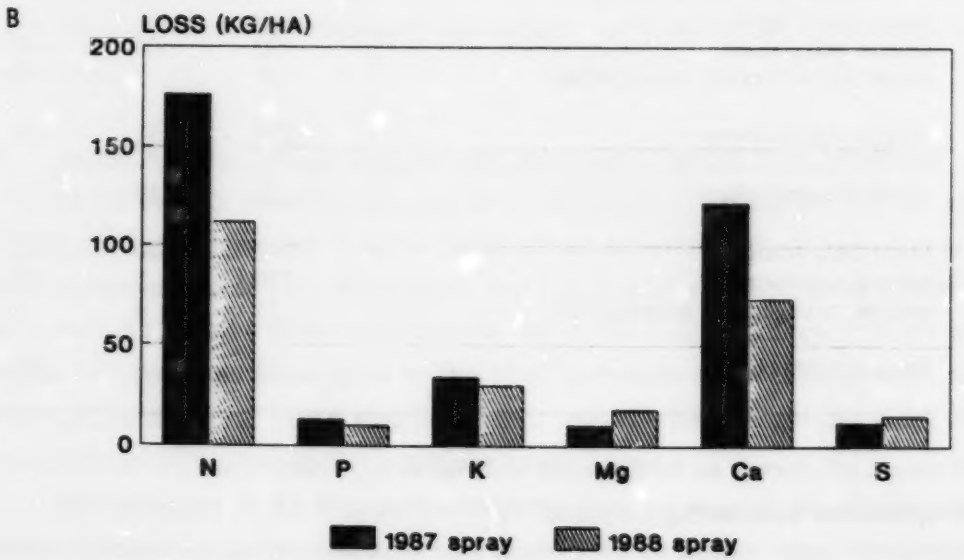


Table 16. Nitrogen, phosphorus, and sulphur changes in the burned ecosystems in the study plots, as a result of the treatments.

Component		N	P	S
1. Comparison between ecosystems				
Xeric -	loss to the atmosphere	172	20	21
	forest floor change	-252	-16	-45
	mineral soil change	70	50	-60
	understory vegetation accumulation	23	4	3
	net ecosystem change	-159	38	-102
Subhygric -	loss to the atmosphere	115	4	6
	forest floor change	-195	-8	-35
	mineral soil change	130	10	-80
	understory vegetation accumulation	26	3	3
	net ecosystem change	-39	5	-112
2. Comparison between treatments				
'87 spray -	loss to the atmosphere	176	13	12
	forest floor change	-229	-12	-37
	mineral soil change	-50	60	-60
	understory vegetation accumulation	25	3	3
	net ecosystem change	-254	51	-94
'88 spray -	loss to the atmosphere	112	10	15
	forest floor change	-217	-10	-42
	mineral soil change	270	0	-70
	understory vegetation accumulation	25	4	3
	net ecosystem change	78	-6	-109

Forest floor and mineral soil changes are for the period July 1988 to July 1989.

Negative values represent decreases during this period.

vegetation growth accumulated 23 - 26 kg/ha of N, presumably withdrawing this from the forest floor and mineral soil.

In the case of P, the relatively small forest floor decreases appear to be more than compensated for by increases in the mineral soil so there appeared to be a net gain in P after the treatment. This gain may not be real, however, as the increases in mineral soil P (50 and 10 kg/ha for the xeric and subhygric ecosystems, respectively) are much smaller than the standard deviations of the mineral soil quantities used to calculate them (Table 12) and were found to be not significantly different from zero (Table 13). With regard to P, it can only be concluded that losses during the burn were relatively low and that the influence of the treatments on ecosystem P status was relatively minor.

In the case of S, forest floor decreases were augmented by mineral soil decreases to produce substantially greater decreases, after allowing for relatively minor plant accumulation of S, than would be suggested by the losses during the burn.

Comparison of the two different treatments indicates no consistent trends among the 3 nutrients. Net decreases were greater for the 1987 herbicide application, in the case of N, but less in the case of P and S, than for the 1988 application. However, as treatment had no significant effect on either forest floor or mineral soil N, P, or S quantities (Tables 10 and 13) any differences in ecosystem nutrient status between treatments may not be very meaningful, particularly since plant uptake of a nutrient was essentially the same in each of the two treatment areas (Table 10).

5.5 Impacts of the Treatments on Vegetation and Planted Tree Seedlings

At the time of planting Douglas-fir seedlings in the study plots (May 1989) understory vegetation cover was 14 - 18% in the xeric and 26 - 29% in the subhygric ecosystems (Table 17). Ecosystem, but not treatment, significantly affected this cover. Although the differences were not statistically significant, there was, however, slightly less plant cover in the 1987 herbicide application area than in the 1988 application area, which was consistent with the slightly greater slash and forest floor consumption in the 1987 application area.

At the height of the first post-treatment growing season, the understory vegetation biomass in the burned area was dominated by *Rubus* spp., *Gaultheria shallon* and grasses in both ecosystems (Table 18). *Epilobium* biomass was relatively low -- less than expected for the area -- but other herbs were important

Table 17. Understory vegetation percent cover at the time of planting seedlings in the study plots in Marc watershed.

Treatment	Ecosystem	
	Xeric	Subhygric
'87 spray	14 (10)[a]	26 (15)[b]
'88 spray	18 (10)[a]	29 (16)[b]
Entire area	16 (10)	28 (16)

Standard deviations are in parentheses
Means followed by different letters are significantly different at $P<0.05$

in both ecosystems as well as other ferns (mainly *Polystichum munitum*) in the subhygric one. Biomass differed significantly between ecosystems only for *Rubus* spp. and *Pteridium aquilinum*, however (Table 19). In light of the distribution of species in recent clearcut and slashburned areas within the University of B.C. Research Forest (Figure 3) it appears that the brown and burn treatment, perhaps together with the recent treatment history of the brown and burn area (previous herbicide application in 1982) has produced early successional plant communities which are relatively depauperate in fireweed (*Epilobium*) but rich in shrubs. This might suggest that shrubs, *Rubus* spp. in particular, are more resistant to browning and burning, than is fireweed. However, uncertainties about seed supplies and influence of the previous herbicide application suggest this statement should be made with caution.

Total understory biomass was not significantly affected by either ecosystem or treatment (Tables 18 and 19) although treatment did affect the biomass of *Gaultheria shallon* and mosses (less in the 1987 application area), and *Pteridium aquilinum* (greater in the 1987 application area).

The study area was clearcut in 1973. The subsequent regrowth of vegetation was sufficient to overwhelm many of the planted Douglas-fir seedlings and render the area N.S.R. The biomass of the understory vegetation in 1975 after two post harvest growing seasons averaged 172.2 gm/m^2 over the watershed (cf. Figure 1 - unburned area in Feller 1988) and was thus similar to what it was only one growing season after the brown and burn treatment. Although the understory vegetation is growing more rapidly after the brown and burn treatment than after

Table 18. Understory vegetation biomass (g/m^2) in the burned area during the first post-treatment growing season, averaged by treatment.

Species	Ecosystem/treatment					
	Xeric			Subhygric		
	'87 spray(blocks 2,3,5)	'88 spray(blocks 1,4,6)	Entire area	'87 spray(blocks 2,3,5)	'88 spray(blocks 1,4,6)	Entire area
Salix spp.	0.1 (0.3)	0.0 (0.1)	0.1 (0.2)	0.1 (0.3)	0.4 (0.8)	0.2 (0.4)
Other hardwoods	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.2 (0.6)	0.1 (0.3)
Gaultheria	8.2 (11.5)	55.3 (38.8)	31.8 (20.2)	11.0 (9.8)	41.4 (30.4)	26.2 (16.0)
Rubus spp.	80.3 (22.8)	85.0 (36.0)	82.7 (21.3)	49.6 (14.1)	58.5 (24.3)	54.1 (14.1)
Vaccinium spp.	0.0 (0.0)	0.3 (1.1)	0.2 (0.6)	0.9 (2.5)	1.2 (2.9)	1.1 (1.9)
Other shrubs	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Pteridium	4.8 (12.9)	0.0 (0.0)	2.4 (6.5)	28.4 (26.0)	1.6 (2.3)	15.0 (13.1)
Other ferns	7.3 (18.7)	0.0 (0.0)	3.7 (9.4)	38.8 (55.6)	8.2 (12.3)	23.5 (28.5)
Epilobium	2.6 (6.4)	0.0 (0.0)	1.3 (3.2)	1.7 (3.6)	1.2 (3.6)	1.5 (2.6)
Other herbs	18.2 (14.5)	18.2 (11.4)	18.2 (9.2)	40.2 (15.5)	18.4 (11.2)	29.3 (9.6)
grasses	23.2 (27.3)	22.0 (17.8)	22.6 (16.3)	19.8 (15.9)	40.4 (30.9)	30.1 (17.4)
moss	0.7 (1.9)	14.4 (20.8)	7.6 (10.4)	3.9 (5.5)	9.5 (8.8)	6.7 (5.2)
Total	145.4 (46.6)	195.2 (60.7)	170.3 (38.3)	194.4 (67.9)	181.0 (53.4)	187.7 (43.2)

Standard deviations are in parentheses

Table 19. Significance of the effects of treatment and ecosystem on the first year postburn biomass of the dominant plant species in the study plots in Marc watershed.

	Species								
Comparison	*Gaultheria*	*Rubus*	*Pteridium*	other ferns	*Epilobium*	other herbs	grasses	moss	Total
Treatment (TRT)	*	-	*	-	-	-	-	*	-
Ecosystem (ECO)	-	*	*	-	-	-	-	-	-
TRT X ECO	-	-	*	-	-	-	-	-	-

Results are from analyses of variance
* indicates a significant effect at $P<0.05$

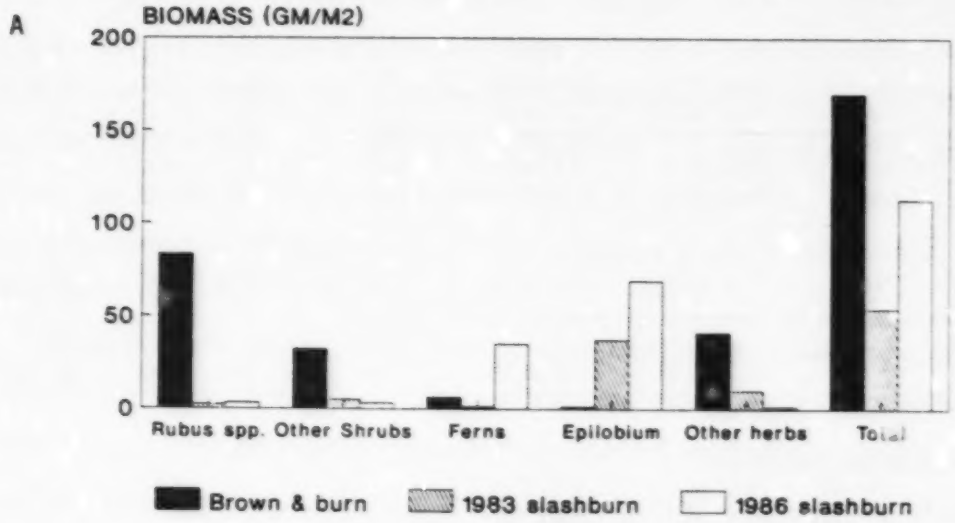
the previous clearcutting, and after other clearcutting and slashburning treatments near the study area (Figure 4) there may be some major differences in species composition between the brown and burned area and these other areas, however, which could be prolonged. Hardwoods, particularly *Alnus rubra* and *Betula papyrifera*, which grew rapidly to dominate the biomass within a few years after the 1973 clearcutting may not develop after browning and burning. In 1989, hardwoods comprised a negligible proportion of the biomass (Table 18). Whether it will remain this way or whether they will develop as they did previously remains to be seen, however.

The Douglas-fir seedlings planted in the study area initially looked as if they would mostly die. However, a recovery during the middle of the growing season resulted in only slight mortality (<5%) in all areas except block 1, where mortality was 21% in xeric and 24% in subhygric ecosystems (Table 20). As block 1 was planted first by inexperienced planters, it is possible that planting technique contributed to this relatively high mortality. Mortality, or survival, did not differ significantly between ecosystem or treatment (Table 20).

Initial tree height did not differ significantly between either ecosystems or treatments (Table 20). This will allow future comparisons of tree heights to be made with confidence so that if differences do become apparent they can be attributed to factors other than initial differences.

First-year height increment ranged from 7 to 12 cm. It did not differ between ecosystems but did between treatments (Table 20). The height increment was

Figure 4. First-year postburn biomass of understory vegetation in the study area (brown and burn) and two nearby clearcut and slashburned areas in xeric (A) and subhygric (B) ecosystems.



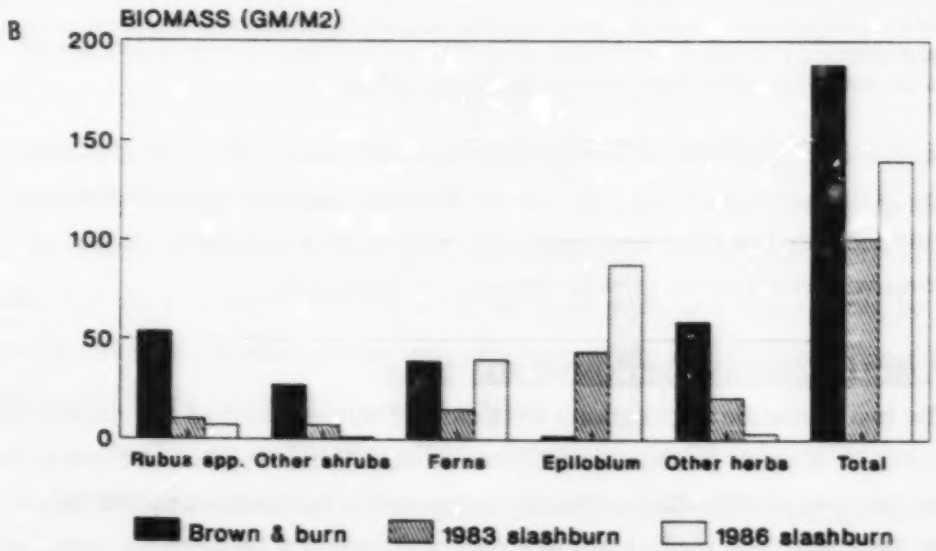


Table 20. Initial height (cm), first-year height increment (cm), and survival (%) of the Douglas-fir seedlings planted in the study blocks.

	Xeric			Subhygric		
Block	Survival	Initial height	Increment	Survival	Initial height	Increment
1	79	77.2 (13.7)	7.8 (3.3)	76	77.3 (12.1)	8.3 (3.9)
2	100	76.4 (9.2)	10.3 (5.3)	97	74.4 (8.4)	10.4 (5.5)
3	95	76.4 (8.4)	8.7 (4.1)	98	72.6 (11.6)	12.2 (5.8)
4	98	77.1 (8.5)	9.3 (9.0)	100	74.6 (11.3)	9.7 (5.4)
5	97	75.6 (9.8)	9.2 (4.7)	100	78.3 (8.5)	6.6 (2.4)
6	97	74.3 (8.7)	6.3 (2.3)	95	72.3 (10.0)	7.0 (3.0)
'87 spray (blocks 2,3,5)	91	76.1 (5.5)	9.7 (2.8)	90	75.1 (5.6)	9.7 (2.8)
'88 spray (blocks 1,4,6)	97	76.2 (6.1)	7.8 (3.3)	98	74.7 (6.4)	8.3 (2.4)
Comparison between ecosystems						
Xeric	94 (8)	76.0 (4.2)	8.8 (2.1)			
Subhygric	94 (9)	74.9 (4.3)	9.0 (1.8)			
Comparison between treatments						
'87 spray	98 (2)	75.4 (4.0)	9.8 (2.0)[a]			
'88 spray	91 (10)	75.5 (4.4)	8.1 (2.0)[b]			

Standard deviations are in parentheses.
For each of the comparisons, means of a given variable followed by different letters are significantly different at $P<0.05$.
Pairs of means not followed by letters are not significantly different.

greater in the 1987 application area than in the 1988 area. However, the average difference in the increment was only 1.7 cm and first year tree growth does not necessarily indicate the long-term response. Future measurements should give a more definitive picture of the growth response to treatment.

6.0 CONCLUSIONS AND RECOMMENDATIONS

The two herbicide applications were carried out as planned but conducting the burn late in the year under relatively moist conditions resulted in a low severity fire. This resulted in little discrimination between the herbicide treatments. Although there were few statistically significant differences between the two

treatments in terms of their effects on fuels, soil, and vegetation, the general trend was that the 1987 herbicide application treatment resulted in greater fuel consumption, nutrient loss, and retardation of growth of competing vegetation, as well as greater height growth of planted Douglas-fir seedlings. The nutrient losses during the burn were relatively small but consistent with other slashburns in the Coastal Western Hemlock zone, with respect to the losses expected in relation to forest floor depth of burn. By the height of the first post-treatment growing season there were no consistent trends among N, P and S in the treatment-caused changes in ecosystem nutrient status, when comparing either ecosystems or treatments.

Although there were no differences between treatments in survival of planted Douglas-fir seedlings, first-year height growth of seedlings was greater in the 1987 application area, but did not differ significantly between ecosystems. Regrowth of competing vegetation was relatively rapid in comparison to the regrowth that occurred following clearcutting of the study area in 1973.

In light of this relatively rapid regrowth of vegetation and the uncertainty over the longer-term growth responses of the planted seedlings, it is recommended that continued monitoring of the vegetation growth occur in the area, and that the ecosystem nutrient status be further assessed after two more growing seasons.

As the burn was conducted under much less than optimum conditions, it is recommended that a similar study be repeated, but using a more severe burn conducted under drier conditions. This is necessary to allow definitive conclusions to be made about the effectiveness of the two brown and burn treatments. At this point it appears as if browning with glyphosate one year in advance of burning is more effective than browning and burning the same year, but this can not be definitively stated at present, due to only relatively slight differences between the two treatments being found in the present study.

It can also be concluded that it is feasible to broadcast burn herbicided areas in the CWHdm subzone the year after, as well as the same year as, herbicide application.

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9.0 APPENDICES

APPENDIX I

SOME MINERAL SOIL PHYSICAL PROPERTIES IN THE STUDY AREA

Mineral soil (0-20 cm) bulk density and coarse fragment content within the study area in Marc watershed.

Ecosystem	Bulk density (kg/m^3)	Coarse fragment (>2mm) content (%)
Xeric	500 (120)	60 (12)
Subhygric	510 (150)	60 (11)

Bulk density is mass of <2mm fraction per unit volume
Standard deviations are in parentheses
n = 20 for each value

APPENDIX 11

PRE- AND POST-BURN ABOVEGROUND BIOMASS
AND ITS NUTRIENT CONTENT

Biomass and nutrient content (kg/ha) of organic material above the mineral soil surface before and after the 1988 slashburn in Marc watershed, averaged by ecosystem and treatment.

Ecosystem/treatment component	Biomass	Nutrient Quantity					
		N	P	K	Mg	Ca	S
Xeric							
'87 Spray							
Living vegetation	1,490 - 240	16.1 - 2.6	1.5 - 0.2	12.4 - 2.0	2.2 - 0.4	9.3 - 1.5	2.1 - 0.4
Slash	145,800 - 124,000	175.9 - 131.9	20.4 - 16.0	33.5 - 26.2	17.0 - 13.1	142.6 - 88.3	36.2 - 30.4
Forest floor	62,050 - 44,850	591.3 - 438.7	41.0 - 23.8	75.1 - 45.7	48.4 - 39.9	323.9 - 235.0	83.8 - 74.5
Total	209,340 - 169,090	783.3 - 573.2	62.9 - 40.0	121.0 - 73.9	67.6 - 53.4	475.8 - 324.8	122.1 - 105.3
'88 Spray							
Living vegetation	4,230 - 1,520	38.0 - 13.7	3.4 - 1.2	25.1 - 9.0	7.8 - 2.8	35.3 - 12.6	5.7 - 2.1
Slash	151,770 - 136,530	190.3 - 153.5	21.9 - 18.3	39.4 - 31.4	19.3 - 15.5	153.4 - 109.5	38.1 - 33.7
Forest floor	48,520 - 41,700	489.6 - 416.2	32.5 - 22.1	54.8 - 42.5	51.9 - 37.1	225.6 - 218.5	85.4 - 69.2
Total	204,520 - 179,750	717.9 - 583.4	57.8 - 41.6	119.3 - 82.9	79.0 - 55.4	414.3 - 340.6	129.2 - 105.0
Subhygric							
'87 Spray							
Living vegetation	1,690 - 420	18.3 - 4.6	1.7 - 0.4	14.0 - 3.4	2.5 - 0.6	10.6 - 2.7	2.4 - 0.6
Slash	145,800 - 124,000	175.9 - 131.9	20.4 - 16.0	33.5 - 26.2	17.0 - 13.1	142.6 - 88.3	36.2 - 30.4
Forest floor	46,470 - 37,400	474.5 - 428.2	20.9 - 23.6	55.8 - 53.5	41.8 - 41.5	232.8 - 202.0	63.7 - 63.6
Total	193,960 - 161,820	668.7 - 527.3	43.0 - 40.0	103.3 - 83.1	61.3 - 55.2	386.0 - 293.0	102.3 - 94.6
'88 Spray							
Living vegetation	4,630 - 1,810	41.5 - 16.3	3.7 - 1.4	27.4 - 10.7	8.6 - 3.4	38.6 - 15.0	6.3 - 2.5
Slash	151,770 - 136,530	190.3 - 153.5	21.9 - 18.3	39.4 - 31.4	19.3 - 15.5	153.4 - 109.5	38.1 - 33.7
Forest floor	50,910 - 45,310	554.4 - 527.9	23.4 - 24.9	63.1 - 64.8	53.5 - 50.3	249.0 - 244.7	73.8 - 77.0
Total	207,310 - 183,650	786.2 - 697.7	49.0 - 44.6	129.9 -106.9	81.4 - 69.2	441.0 - 369.2	118.2 - 113.2

All data have been corrected for percentage of area burned.

APPENDIX III

ORGANIC MATTER CONSUMPTION AND NUTRIENT LOSS TO THE ATMOSPHERE DURING THE SLASHBURN

Organic matter consumption and nutrient loss to the atmosphere (kg/ha) during the 1988 slashburn in Marc watershed, averaged by ecosystem and treatment.

Ecosystem/ treatment	Organic matter consumption	Loss					
		N	P	K	Mg	Ca	S
Comparison between ecosystems							
Xeric	32,510	172.3	19.6	41.8	18.9	112.4	20.5
Subhygric	27,900	115.0	3.7	21.6	9.2	82.4	6.4
Comparison between treatments							
'87 Spray	36,200	175.8	13.0	33.7	10.2	122.0	12.3
'88 Spray	24,220	111.5	10.3	29.7	17.9	72.8	14.6

Data were calculated from data given in Appendix II.
Differences in organic matter consumption between this table and table 4 are explained by the fact that data in Table 4 were derived for each block by weighting the consumption in an ecosystem by the proportion of the block occupied by that ecosystem relative to the proportion occupied by the other ecosystem. The treatment comparison data in this Table were derived by taking a simple average of the values for both ecosystems.